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Timeline

- Project start date: Aug. 1, 2009
- Project end date: July 31, 2012
- Percent complete: 25%

Budget

- Total project funding: \$11MM
 - DOE share: \$3MM
 - DuPont Share: \$8MM
- Funding received in FY09: None
- Funding for FY10: \$1MM

Barriers

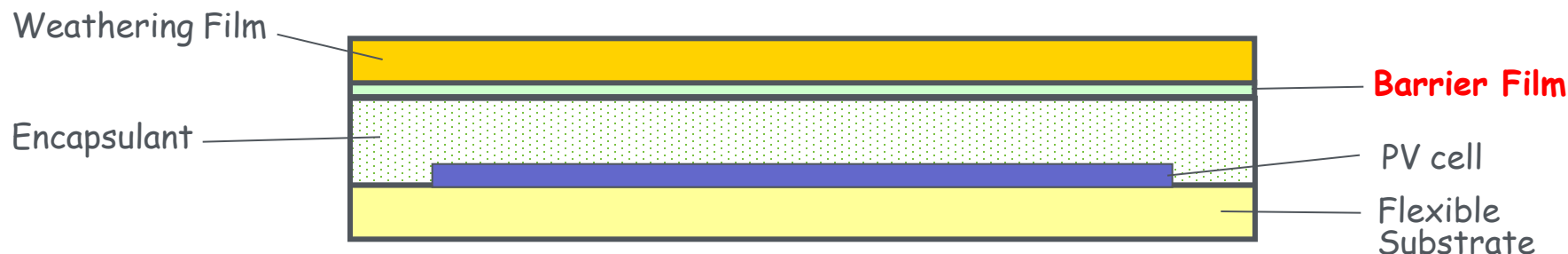
- Barriers addressed
 - Design and **packaging**
 - Manufacturing process
 - Material utilization & **cost**

Partners

- Parallel collaboration effort with:
 - Two industrial partners
 - Two academic partners
 - Market partners
 - All outside of DOE program

- Flexible CIGS can drive installed PV cost reduction and enable improved BIPV products for grid parity
 - Highest efficiency among thin-film PV options (ca. 20% in lab (NREL), 13% on module)
 - Lower manufacturing cost (fewer materials, roll-to-roll economy of scale)
 - Lower installation cost (lighter modules, no frames)
- However, moisture accelerates CIGS cells degradation
- Flexible transparent ultra barrier is needed

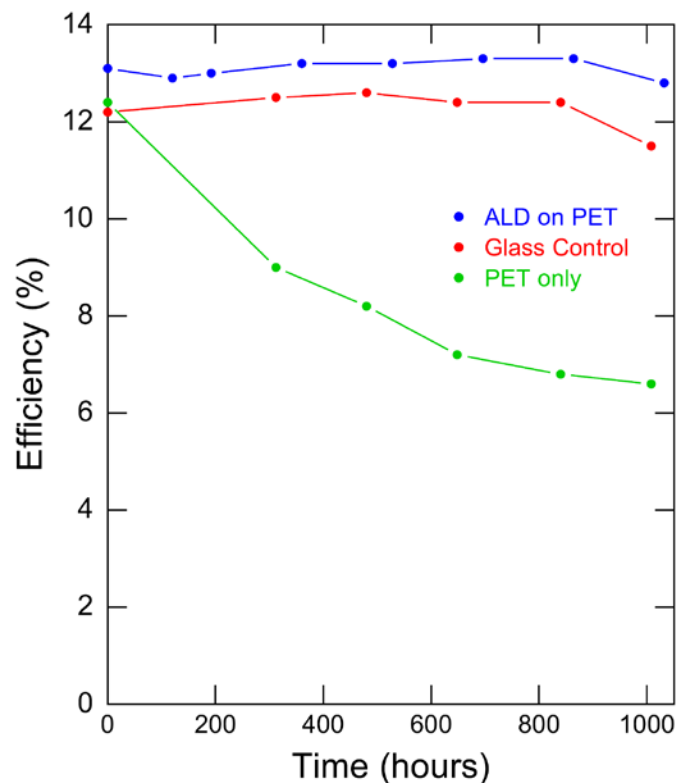
Model frontsheet barrier/encapsulation of PV cell



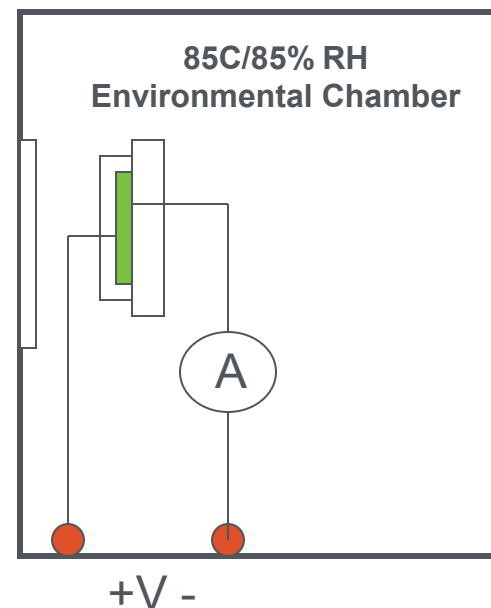
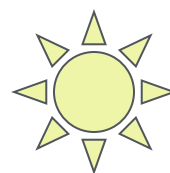
Relevance - Flexible Ultra Barrier Enables CIGS on Flex

- Our initial lab results indicated that ALD-on-plastic could effectively protect CIGS cell
- Program goal here is to demonstrate manufacturing feasibility of ALD-on-plastic with water vapor transmission rate below 10^{-4} g/m²/day at low cost

85C/85 % RH with illumination for 1032 hr

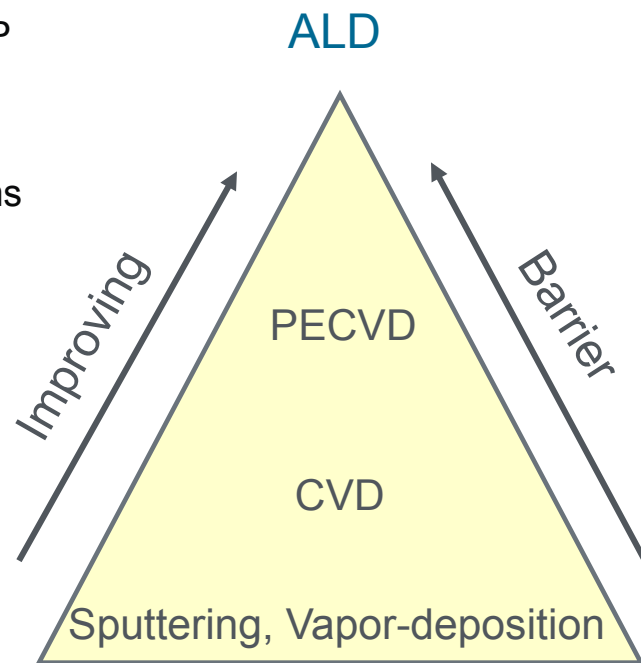
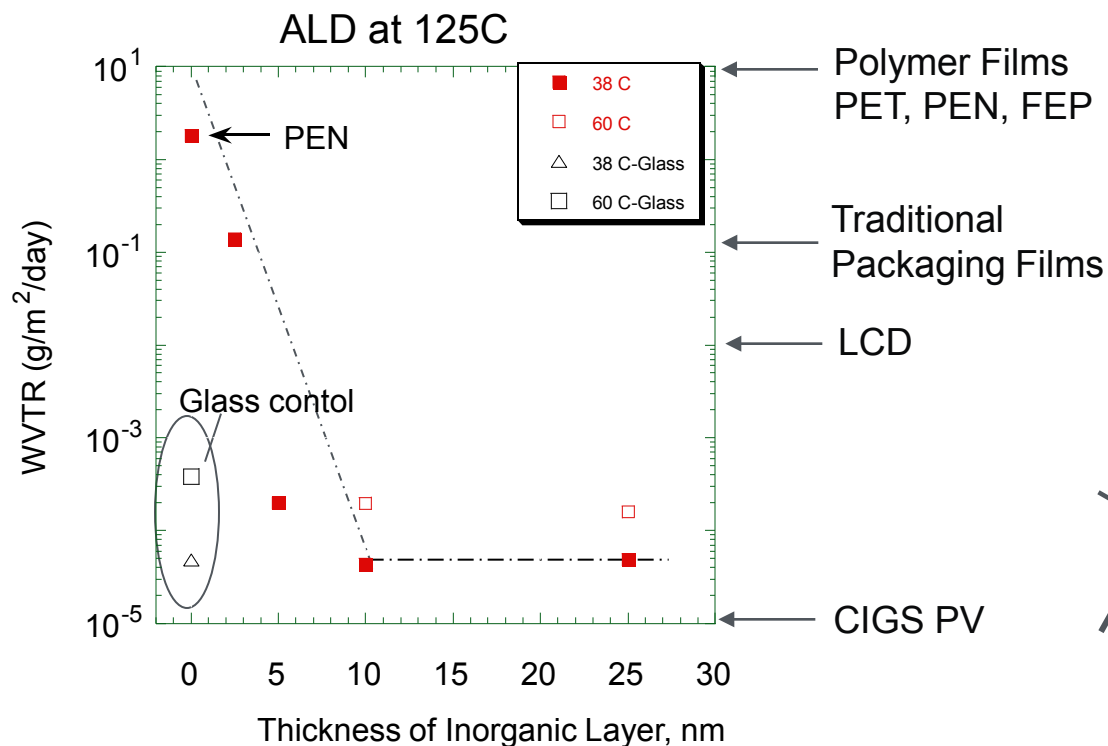
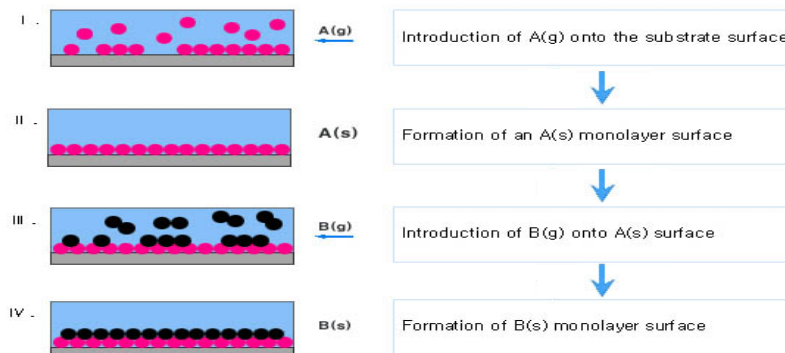


Measured at partner institute



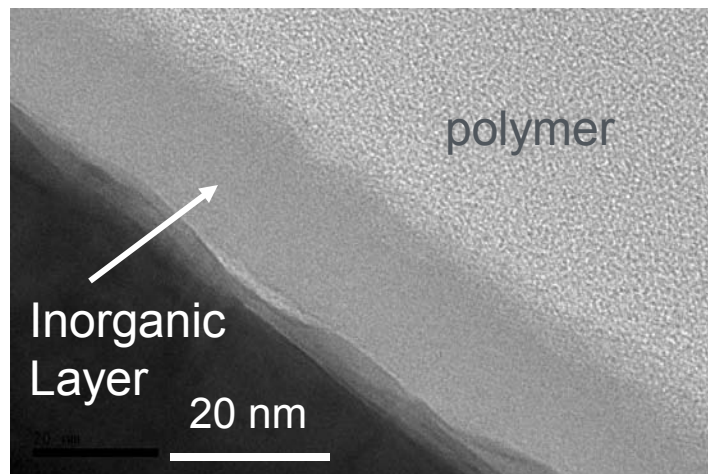
Approach - Atomic Layer Deposition (ALD) on plastic

- Simple process
- Compatible with plastics
- Final film product is transparent and flexible
- $WVTR < 10^{-4} \text{ gH}_2\text{O/m}^2/\text{day}$



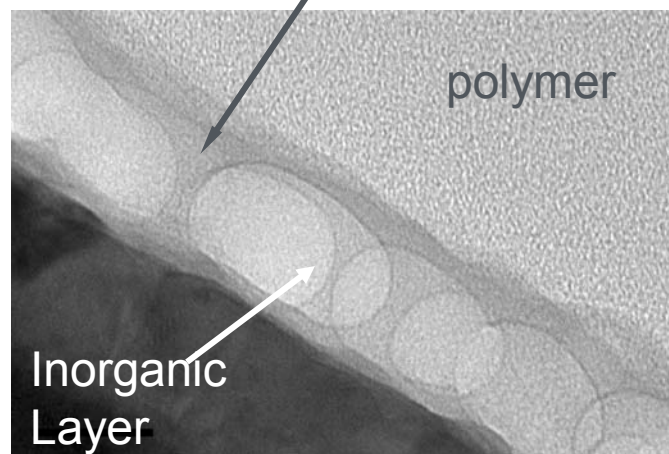
ALD vs. Vapor Deposition - TEM Images

Inorganic
layer
on polymer
by ALD

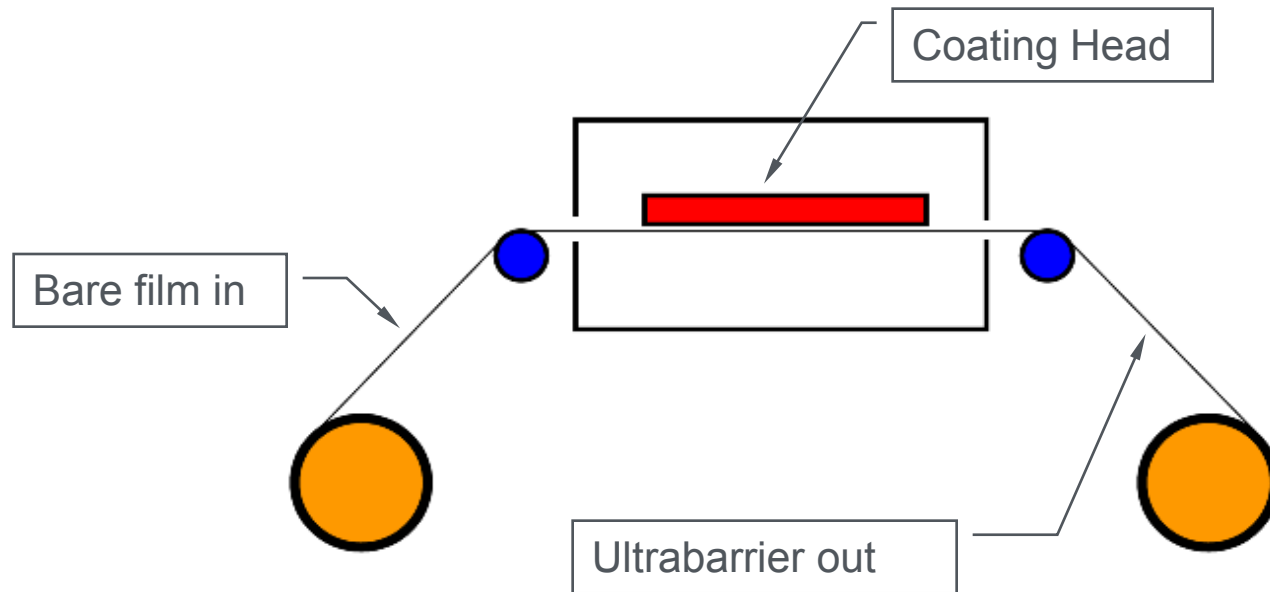


Grain boundaries =
water transmission

Inorganic layer
on polymer
by vapor deposition

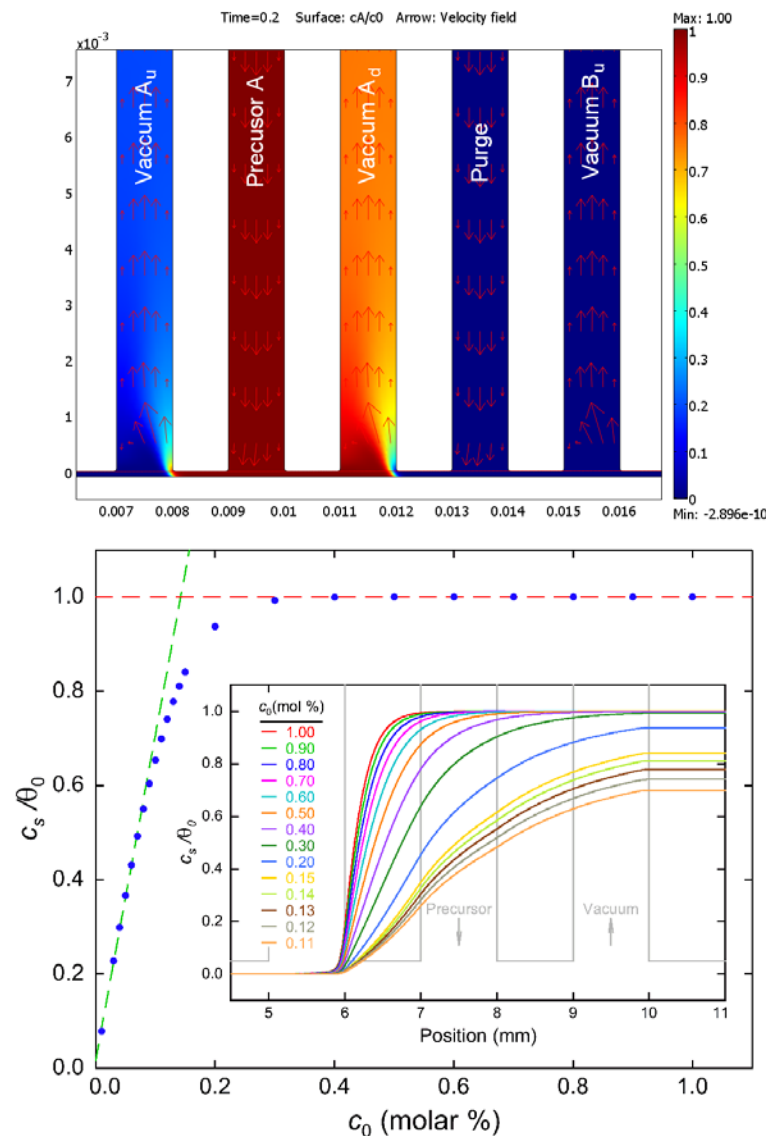


- Build prototype to demonstrate that ALD-on-Plastic can be manufactured with high throughput at low cost.



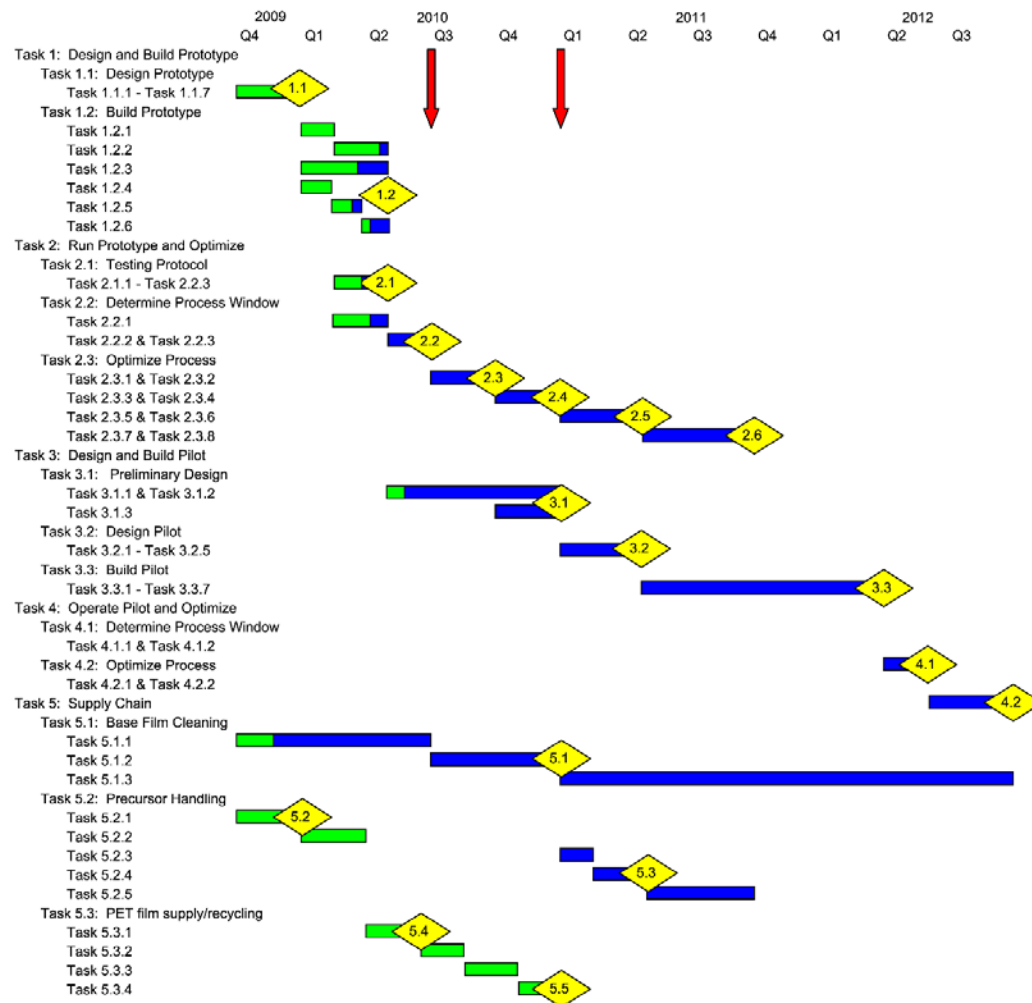
- Proprietary coating head enables roll to roll manufacturing
 - Design confirmed by computational fluid dynamics & numerical modeling
- Model indicates feasibility of 1 m/sec web speed
 - Initial target is 0.1 m/sec
 - Process self-stabilizes in ~ 0.1 sec
 - Negligible cross-talk between precursors
- Optimization from model
 - Shown process stable against expected variations in head to web gap
 - Explored materials efficiency: precursor concentration can be reduced to 0.4%

Take-home message: Modeling predicts feasibility



Results – Progress and Plan for Continuous Process Commercialization

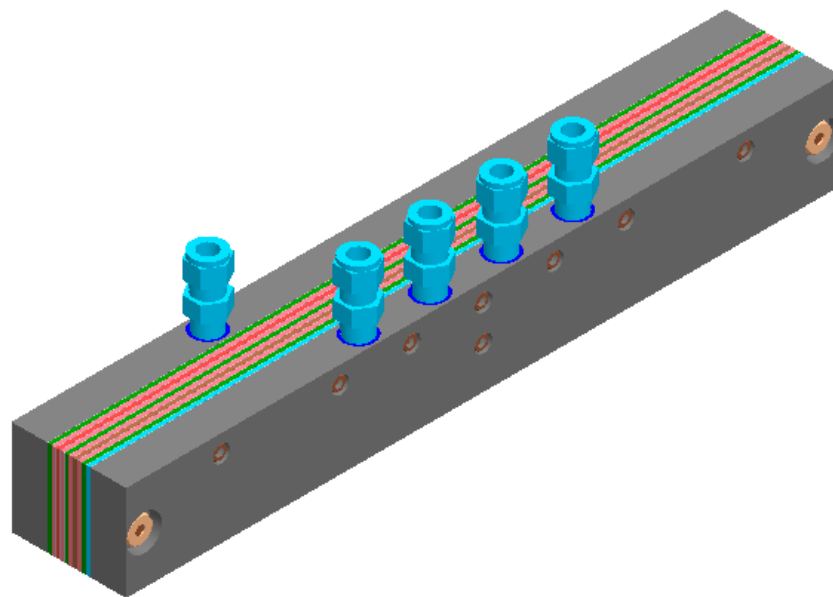
- **GEN 1: Prototype**
 - PET belt (3m x 0.5m)
 - Start up June, 2010
 - First go/No go decision in July 2010
- **GEN 2: Pilot plant**
 - Continuous web at commercial speed
 - Pilot in place by June, 2012



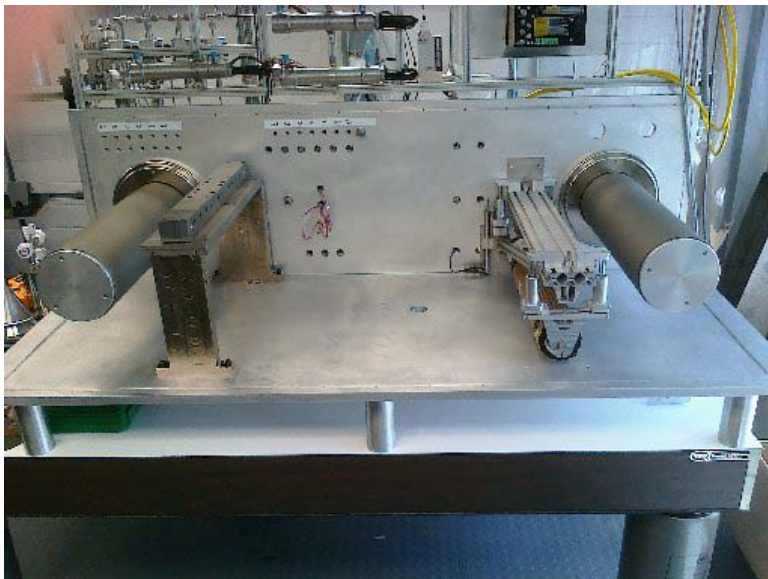
Take home message: Progressing against plan

- Prototype equipment design completed, including:
 - Reaction kinetic analysis for process window
 - Gas delivery and pressure control system
 - Film transport system
 - Deposition chambers and coating head
 - Thermal control system
 - Process control strategy
- PET film supply secured
- Used film recycling plan in place

Take-home message: Prototype design completed. PET film supply secured.



- Prototype fabrication 85% complete
 - System components procured
 - Prototype in assembly
- Implementing process control strategy



Take-home message: Prototype fabrication nearly complete.

- **June 30, 2010**
 - Prototype fabricated, testing protocol in place
- **December 31, 2010**
 - Prototype process parameters documented
 - Prototype optimized, with WVTR below $5\text{E-}4 \text{ gH}_2\text{O/m}^2/\text{day}$
 - Documented procedure of PET film cleaning to achieve WVTR below $1\text{E-}4 \text{ gH}_2\text{O/m}^2/\text{day}$
- **March 31, 2011**
 - Preliminary design of pilot facility in place
- **September 30, 2011**
 - Prototype optimized, with WVTR below $1\text{E-}4 \text{ gH}_2\text{O/m}^2/\text{day}$
 - Pilot facility design completed
- **June 30, 2012**
 - Pilot facility built

- Two university partners (US-based)
 - CIGS cells aging tests using our ALD barrier films
 - Exploring ALD barrier material set
- Market partners (US-based)
 - Working with CIGS module makers to evaluate our barrier film
- Two industrial partners (US-based)
 - Evaluating contingency for high throughput ALD-on-plastic

- ALD-coated polymer improves moisture stability of CIGS cells
- Modeling predicts that ALD-on-plastic can be produced at high throughput
- Prototype equipment design completed
- Prototype equipment fabrication near completion
- Polymer substrate supply secured and recycle plan in place
- Collaborating with academic and industrial partners, as well as market partners
- Making progress against plan for pilot plant